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Patentanmeldung Nr. Patent application No. Demande de brevet n°

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Der Präsident des Europäischen Patentamts;
Im Auftrag

For the President of the European Patent Office

Le Président de l'Office européen des brevets
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R C van Dijk

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Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
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Digital control apparatus for a switching DC-DC converter

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"Digital control apparatus for a switching DC-DC converter."

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DESCRIPTION

The present invention refers to a digital control apparatus for a switching DC-DC converter.

There is presently a continuous evolution of the computers and above all of the microprocessors. The need to process an always greater quantity of information in the shortest possible time has brought to manufacture high performance microprocessors that require high currents (which have a value of multiply of ten ampere) for operation thereof. For this reason devices able to provide a low supply voltage and a high current have been manufactured.

However, the present microprocessors do not require high currents in continuous way but only in prefixed time periods; this is due to the quantity of operations that must be performed in said time periods. Therefore the value of the current adsorbed from them must change from multiply of ten milliamperes to 80-100 amperes in short time (some nanoseconds).

Said devices are power supplies comprising switching DC-DC converters as, for example, the step-down converter shown in Figure 1. Said converter comprises a MOS power transistor M having a non-drivable terminal connected with an inductor L that in turn is connected with a real capacitor constituted by a capacitor Cr and a resistor R and which is placed in parallel with a load LOAD, for example a microprocessor. When the load LOAD has an abrupt variation, the average current that flows through the inductor cannot rise quickly to the value required by the load LOAD and the capacitor is discharged. The waveform of the output voltage Vout, which is shown in Figure 2a, will have a negative and positive voltage variation, respectively, at the start and at the end of the time period wherein a high current value is required by the load LOAD. If the variation of the current Iload (Figure 2b) on the load is given by ΔI, the instantaneous voltage variation will be, in first approximation, $\Delta V = \Delta I * R$.

The switching DC-DC converters are provided with control devices normally placed between the output and the driving terminal of the power transistor of said converters. The most utilized control devices are of the analogic type but control devices of the digital type are presently being affirmed which present numerous advantages with respect to the analogic control devices. In fact they are less sensitive to the environment variations, are less sensitive to noise, have a less sensitivity to parameter variations and also the change of the control device does not require the change of its components. The last feature allows them to have a higher flexibility with respect to the control devices of the analogic type because it is not necessary to change the electric components of the control device for conforming to the different circuit applications.

The digital control devices are provided with an analogic/digital converter able to measure the output voltage and/or current of the DC-DC converter. The information deriving from the analogic/digital converter is then processed by means of a digital control algorithm. The signal generated by the algorithm is sent to the input of a PWM device the output signal of which is used to drive the power transistor of the DC-DC converter.

However, the digital control devices have a main disadvantage due to the time delay in the control loop that needs for processing the information. For this reason the digital control devices that are now present in commerce do not assure that the supply voltage of the load placed downstream of the DC-DC converter is kept constant without going down a voltage level that is equal to the minimum operation value of the load when the same load requires high currents.

A digital control device for a DC-DC converter is disclosed in the article "Modeling and Simulation of new digital control for power conversion systems" Capponi, G.; Livreri, P.; Minieri, M.; Marino, F. Power Electronics Specialists Conference, 2002, pesc 02. 2002 IEEE 33rd Annual, Volume 1, 2002 Pages: 155 –158. In such article a technology of voltage

positioning (VP) is used to minimize the excursion of the output voltage with the load variations. Figure 3 shows the waveform of the output voltage Vo and of the current Iload in the load LOAD of the generic converter in Figure 1 by using the control device that is present in said article: the voltage Vo shows peaks of the order of 400mV with load current variations of the order of 15 A.

In view of the state of the art described, it is an object of the present invention to provide a digital control apparatus for a switching DC-DC converter that allows to lower further the excursion of the output voltage of the converter with the load variations.

According to present invention, such object is obtained by means of a digital control apparatus for a switching DC-DC converter, said converter comprising at least one power transistor and being able to provide a regulated output voltage on a load, said apparatus comprising control digital means having in input a reference digital signal and being able to provide a modulating signal to a PWM device, said PWM device having in input said modulating signal and providing an output square wave signal for driving the power transistor of said DC-DC converter, characterized by comprising digital means able to operate on the square wave signal to obtain that it has a non-linear modulation only when the value of a signal on the load is lower or higher than prefixed value range of said signal on the load.

The features and the advantages of the present invention will be made evident by the following detailed description of embodiments thereof, shown as not limiting examples in the annexed drawings, wherein:

Figure 1 is a circuit scheme of a CC-CC converter according to prior art;

Figures 2a and 2b show the voltage and the current in the load of the converter in Figure 1;

Figure 3 shows the diagrams of the voltage signal Vo and of the current signal Iload in an oscilloscope for the circuit in Figure 1 by using a

digital control device according to prior art;

Figure 4a is a block scheme of a digital control apparatus for a DC-DC converter according to a first embodiment of the present invention;

Figure 4b is a block scheme of a digital control apparatus for a DC-DC converter according to a second embodiment of the present invention;

Figures 5a and 5b show the possible waveform of the output signal of the block PUSH of the device in Figures 4a or 4b;

Figures 6a-6c show time diagrams of the output signals of various circuit blocks present in the scheme in Figure 4a;

Figure 7 shows the diagrams of the voltage signal Vout and of the current signal Iload in an oscilloscope for the DC-DC converter in Figure 4a;

Figures 8-10 are block schemes of a digital control apparatus for a DC-DC converter according to variants of the first and the second embodiment of the present invention.

In Figure 4a a block scheme of a digital control apparatus for a DC-DC converter according to a first embodiment of the present invention is shown. A digital control block 1 receives an input reference voltage Vref, that is a constant digital signal, and provides an output voltage Vc. The digital control block 1 is preferably performed by means of a PID.

The signal Vc is sent in input to a digital/analogic converter 2 providing the correspondent output analogic signal. The last signal and a slope signal SR generated by a device GR are in input to an analogic PWM device 3 able to provide a signal D to drive the power transistor M belonging to a DC-DC converter 4, for example the converter shown in Figure 1.

The output signal Vout of the converter 4 is sent in input to a analogic/digital converter 6; the digital signal Voutd is sent to a block PUSH able to provide a digital signal Vs that is added to or subtracted from the signal Vc in order to carry out a non-linear modulation of the square wave signal D in output from the PWM device 3. The block PUSH is formed by a series of programmable registers and the signal Vs is of the step ramp type

and its duration Dt and its amplitude A are programmable.

The signal Vs is emitted when the output voltage Vout goes under a lower threshold value or rises over a top threshold value, that is when said voltage Vout is out of a prefixed range of the output voltage Vout, for example if the voltage Vout is higher or lower than the 5% of its stationary value; more precisely the signal Vs is emitted during the transitions of the output voltage Vout or of the current Il flowing through the inductor L which are due to a variation of the load LOAD of the converter 4. Also the effect of such signal must not last for a long time, therefore it is necessary that said effect decreases in a gradual way. For these reasons the signal Vs has a waveform as shown in Figures 5a or 5b.

Preferably the output voltage signal Voutd of the converter 6 is sent to an adaptive voltage positioning block (AVP) 5 having in input even a digital signal Vsensed, that is for example the signal Vsense deriving from a sense resistor Rs placed in series with the inductor L of the DC-DC converter which is made digital by the block 6. In the block 5 the digital signal Vsensed is multiplied by the value of the resistor Rs, divided by the value of the resistor R5, which has an equal or different value with respect to the value of the resistor R, and summed to the digital signal Voutd. The resulting signal is in output from the block 5 and is subtracted from the signal Vref and is sent to the block 1.

In Figure 6a the slope signal SR and an analogic signal VM given by the sum or the difference between the modulating signal Vc and the signal Vs are shown. Said sum or difference are due to the positive or negative variations of the output voltage Vout; in fact if the variation of the load LOAD causes an elevation of the voltage Vout a signal Vs as shown in Figure 5b will be obtained; if instead the variation of the load LOAD causes a decrease of the voltage Vout a signal Vs as shown in Figure 5a will be obtained. The output signal D of the PWM block 3 is a non-linear modulated square wave signal (Figure 6b). Said signal D drives the power transistor M

of the DC-DC converter by increasing or decreasing the on time Ton that is by modulating the duty-cycle. In such way the increase of the time Ton causes an increase of the current IL flowing through the inductor L (which is represented by a continuous tract with respect to the sketch tract) for satisfying the current requirement from the load LOAD while a decrease of the Ton time allows the inductor L to be easily discharged and to be quickly brought into the new stationary state.

In Figure 7 the oscilloscope measurements of the voltage signal Vout and of the current signal Iload for the circuit in Figure 4a are shown; it may be noted that the voltage Vout has a voltage drop of 150mV in correspondence of load current variations of the order of 15 A and it does not present the voltage peaks of the signal Vo in figure 3.

In Figure 4b a block scheme of a digital control apparatus for a DC-DC converter according to a second embodiment of the invention is shown. The control apparatus of said second embodiment is different from the control apparatus of the first embodiment for the presence of a digital PWM device 9 instead of the analogic PWM device 3 . In such a way the digital/analogic converter 2 does not occur and the signal to be modulated is of digital type and is generated inside the block 9.

Alternatively, according to variants of the above mentioned embodiments, the signal Vs may be sent in input to the control block 1 (Figure 9) instead that to the PWM device. According to other variants the block PUSH may be controlled by means of a signal present in the sense resistor Rs, that is the current IL or the voltage Vsense proportional to the current IL, which is always a signal proportional to the current variation of the load LOAD; the output signal Vs of the block PUSH may be sent in input to the PWM device (Figure 8) or to the control block 1 (Figure 10). The block PUSH comprises numeric comparators able to compare the output signal Voutd of the converter 6 with said prefixed voltage value range (block PUSH in Figures 4 and 9) or able to compare the voltage signal Vsensed

proportional to the current signal IL or the current signal IL that has been digitalized respectively with a prefixed voltage value range or with a prefixed current value range (block PUSH in Figures 8 and 10), that is for example if the voltage Vsense or the current IL is higher or lower than the 5% of its stationary value. Even if in Figures 8-10 only apparatus as variants of the first embodiment of the present invention are shown, the features of the variants in Figures 8-10 are valid for the second embodiment of the present invention.

CLAIMS

1. Digital control apparatus for a switching DC-DC converter (4), said converter (4) comprising at least one power transistor (M) and being able to provide a regulated output voltage (Vout) on a load (LOAD), said apparatus comprising control digital means (1) having in input a reference digital signal (Vref) and being able to provide a modulating signal (Vc) to a PWM device (3; 9), said PWM device (3, 9) having in input said modulating signal (Vc) and providing an output square wave signal (D) for driving the power transistor (M) of said DC-DC converter (4), characterized by comprising digital means (PUSH) able to operate on the square wave signal (D) to obtain that it has a non-linear modulation only when the value of a signal (Vout, Iload) on the load (LOAD) is lower o higher than prefixed value range of said signal (Vout, Iload) on the load (LOAD).

2. Apparatus according to claim 1, characterized in that the driving of the power transistor (M) comprises the determination of the on time (Ton) and the off time of said power transistor (M), and in that said digital means (PUSH) are able to increase or decrease the on time (Ton) of said transistor (M) with the increase or the decrease of the value of the signal (Vout, Iload) on the load (LOAD) with respect to value range of said signal (Vout, Iload) on the load (LOAD).

3. Apparatus according to claim 1, characterized in that said digital means (PUSH) provide a signal (Vs) formed as a step ramp the amplitude (A) and the duration (Dt) of which are programmable.

4. Apparatus according to anyone of claims from 1 to 3, characterized in that said signal on the load is the output signal (Vout) of the DC-DC converter (4) and said digital means (PUSH) comprise numeric comparators able to compare said output signal (Vout) of the DC-DC converter (4) with a prefixed voltage value range.

5. Apparatus according to anyone of claims from 1 to 3,

characterized in that said signal on the load is a current signal (Iload) and said digital means (PUSH) comprise numeric comparators able to compare a signal (Vsense, Il) proportional to the current signal (Iload) on the load with a prefixed signal value range.

6. Apparatus according to claim 4 or 5, characterized in that the output signal (Vs) of said digital means (PUSH) acts on the input signal of said PWM device (3; 9).

7. Apparatus according to claim 4 or 5, characterized in that the output signal (Vs) of said digital means (PUSH) acts on the input signal of said digital control means (1).

8. Apparatus according to claim 6 or 7, characterized in that said PWM device (3) is of the analogic type and said apparatus comprises a digital/analogic converter (2) able to convert the digital signals (VM) in input to a said PWM device (3).

9. Apparatus according to claim 4 or 5, characterized by comprising means able to generate a ramp signal (SR) in input to said analogic PWM device (3).

10. Apparatus according to claim 6 or 7, characterized in that said PWM device (9) is of the digital type.

11. Apparatus according to anyone of the preceding claims, characterized in that said DC-DC converter (4) comprises at least one inductor (L) having a first terminal connected with a non drivable terminal of said power transistor (M) and a second terminal connected with a capacitor (C) placed in parallel with the load (LOAD), and by comprising a voltage positioning block (5) having in input said output voltage (Vout) and a voltage proportional to the current (IL) flowing through the inductor (L) and sending their difference voltage to the input of said control digital means (1), said voltage difference being subtracted from the reference signal (Vref).

"Digital control apparatus for a switching DC-DC converter."

* * * * *

ABSTRACT

A digital control apparatus for a switching DC-DC converter (4) is described. The converter (4) comprises at least one power transistor (M) and is able to provide a regulated output voltage (Vout) on a load (LOAD). The apparatus comprises control digital means (1) having in input a reference digital signal (Vref) and being able to provide a modulating signal (Vc) to a PWM device (3; 9); the PWM device (3, 9) has in input the modulating signal (Vc) and provides an output square wave signal (D) for driving the power transistor (M) of said DC-DC converter (4). The apparatus comprises digital means (PUSH) able to operate on the square wave signal (D) to obtain that it has a non-linear modulation only when the value of a signal (Vout, Iload) on the load (LOAD) is lower or higher than prefixed value range of said signal (Vout, Iload) on the load (LOAD). (Figure 4a)

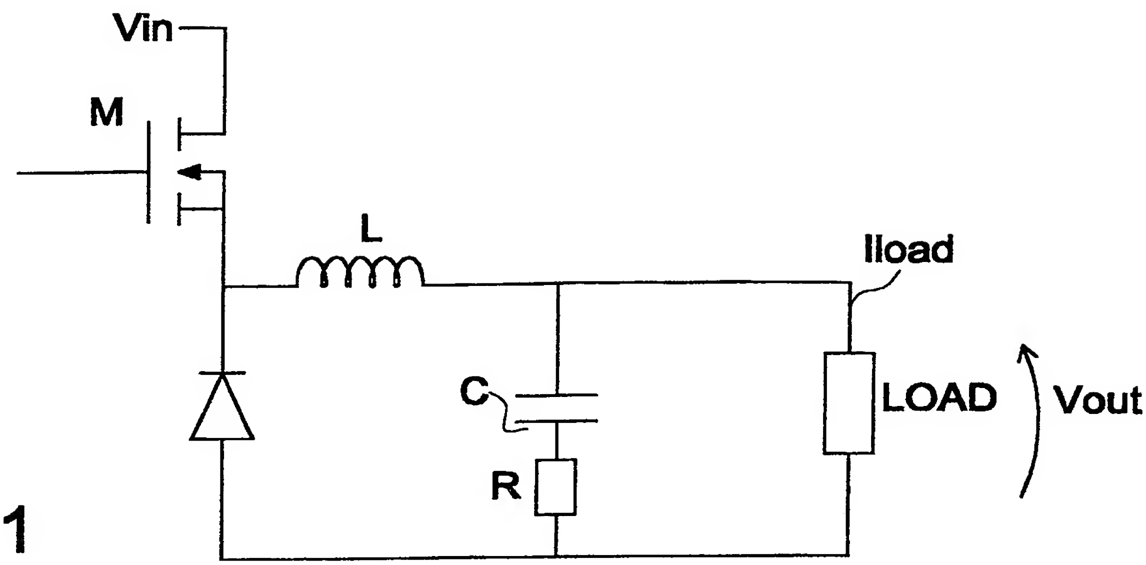

Fig.1

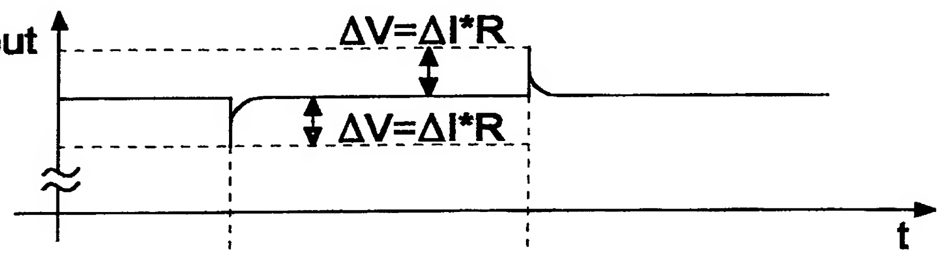

Fig.2a

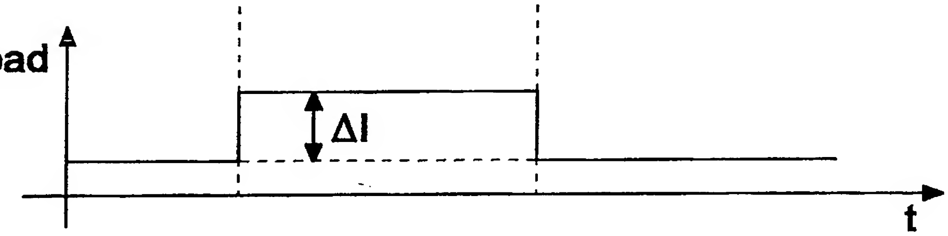

Fig.2b

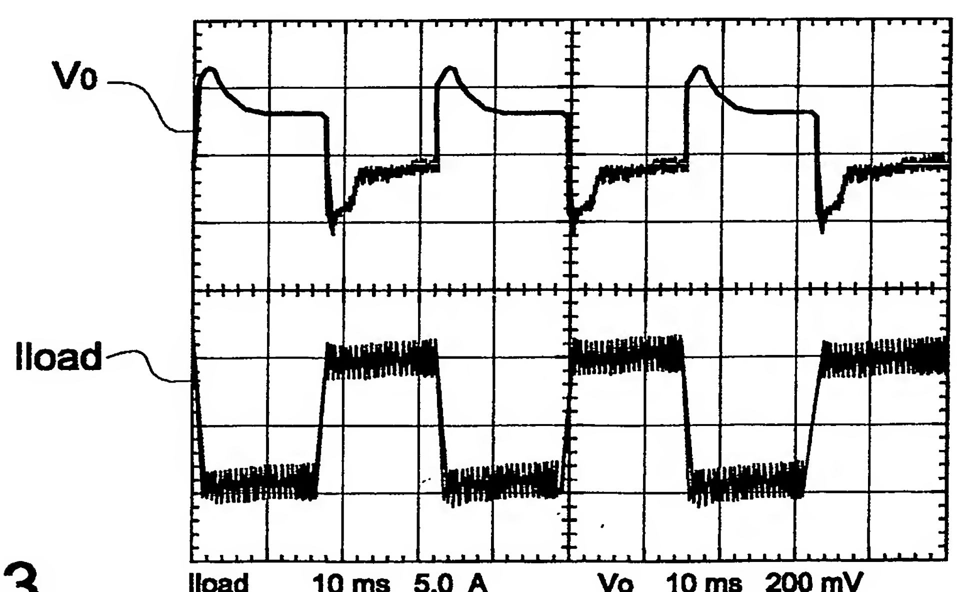

Fig.3

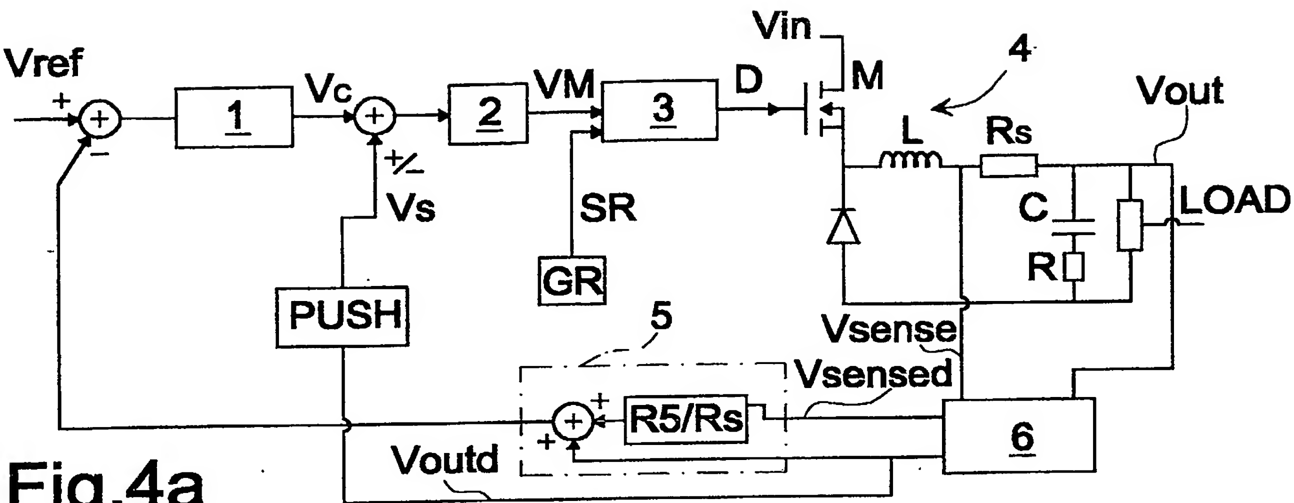

Fig.4a

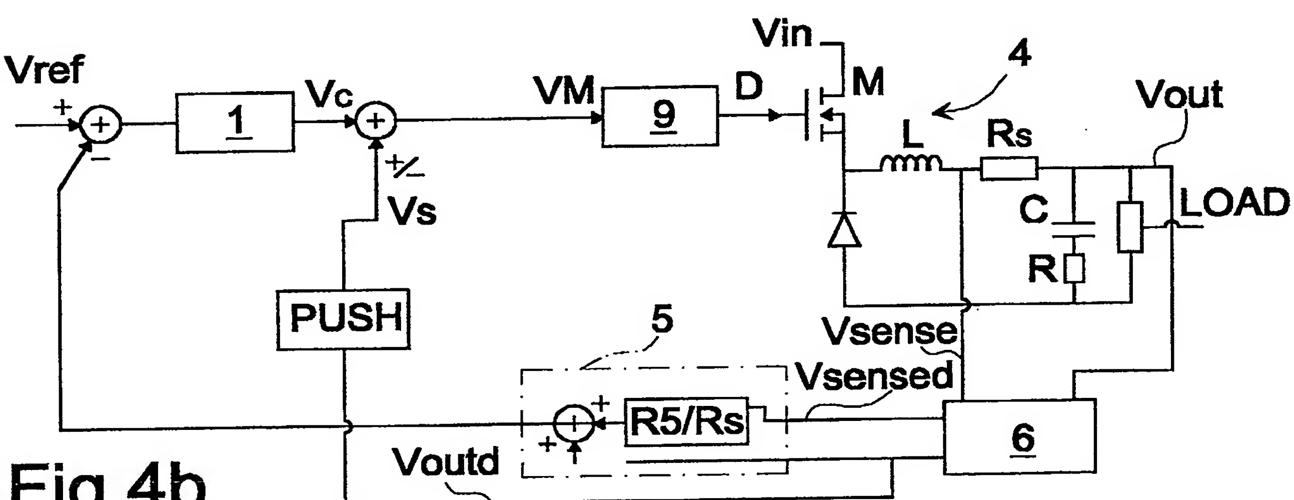

Fig.4b

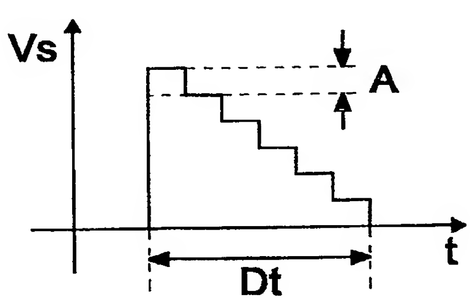

Fig.5a

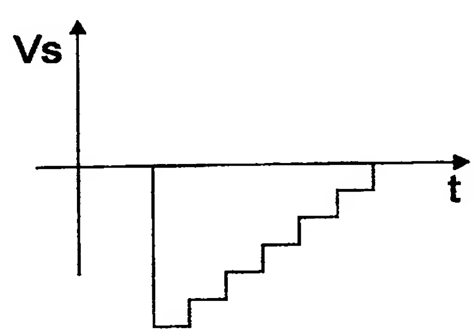

Fig.5b

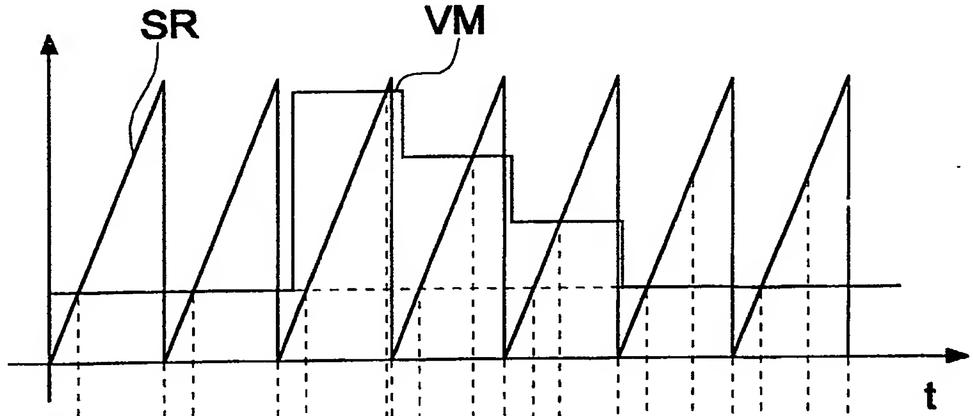

Fig.6a

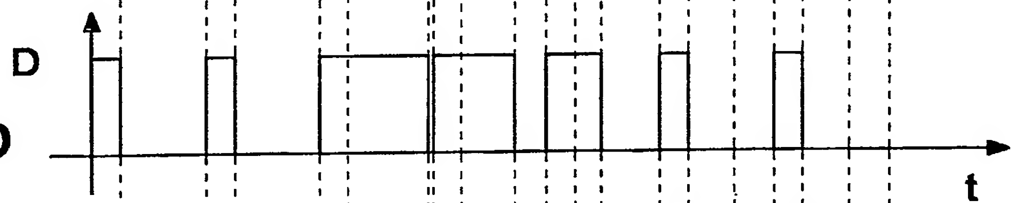

Fig.6b

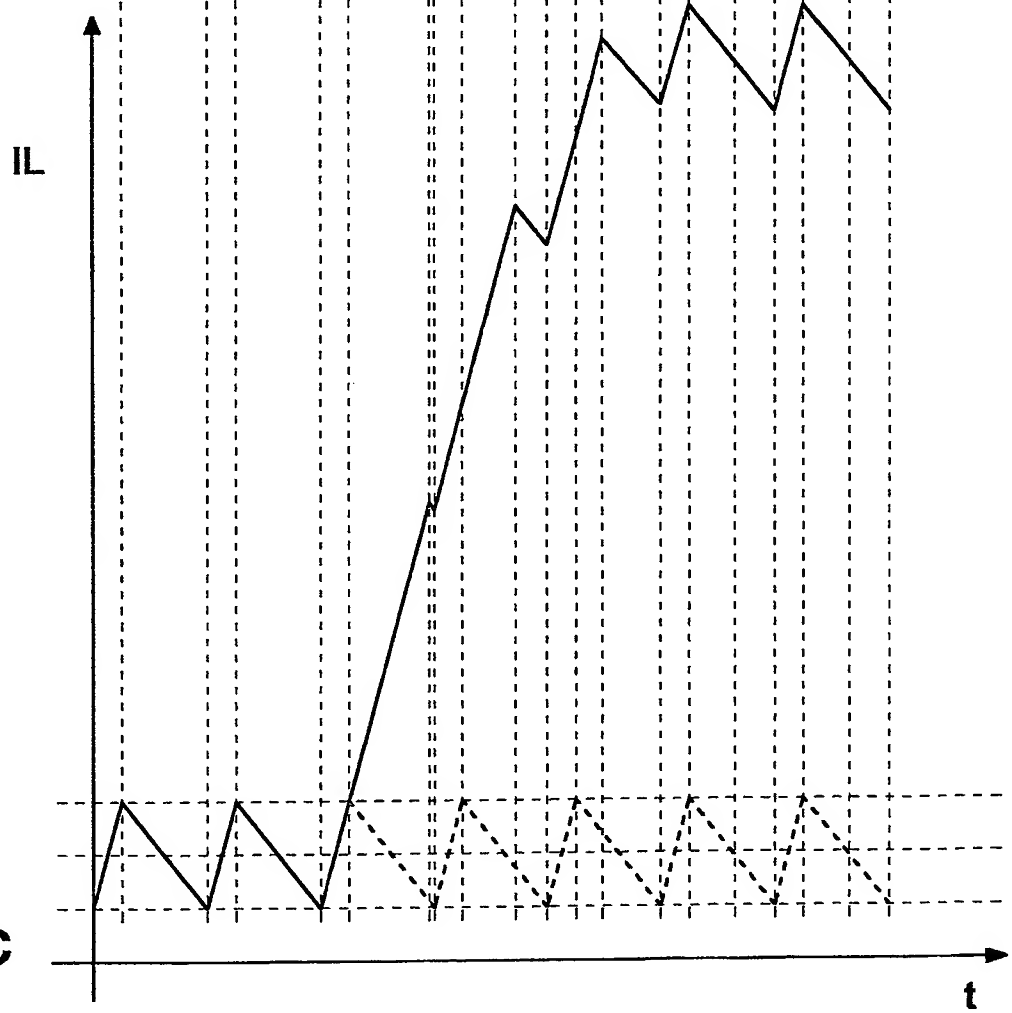

Fig.6c

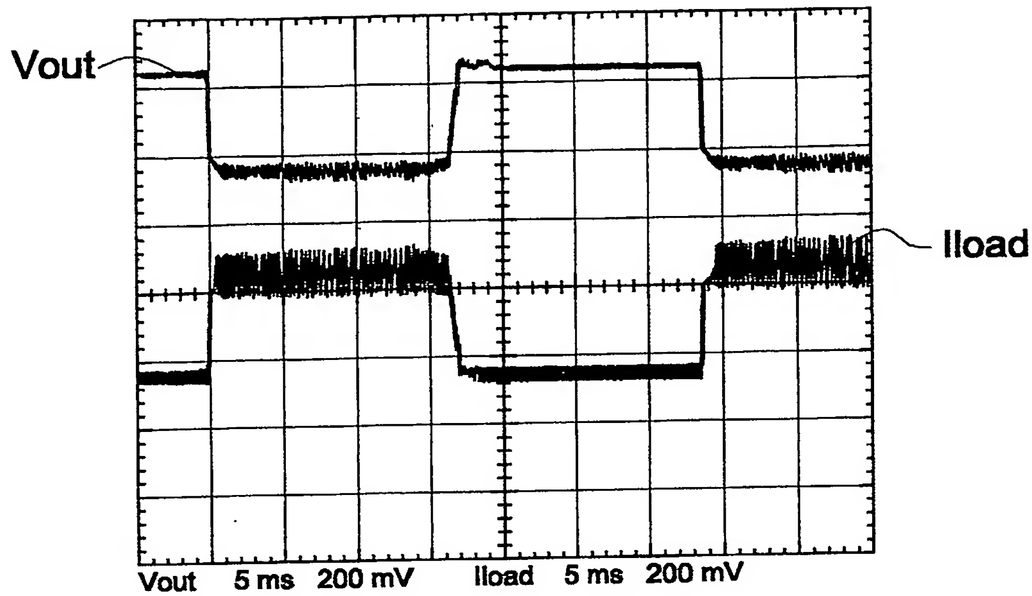

Fig.7

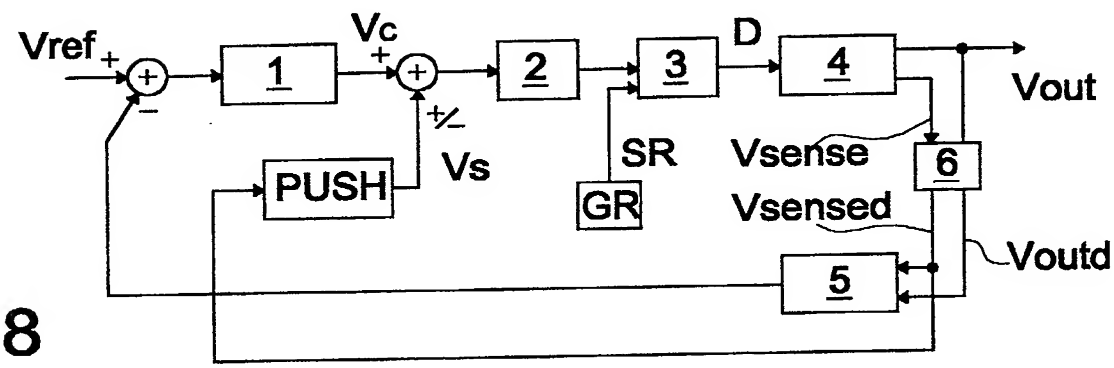

Fig.8

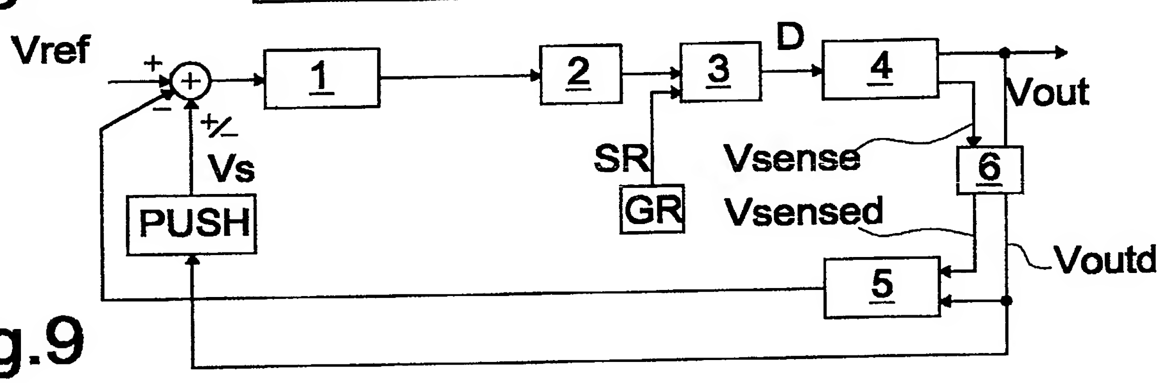

Fig.9

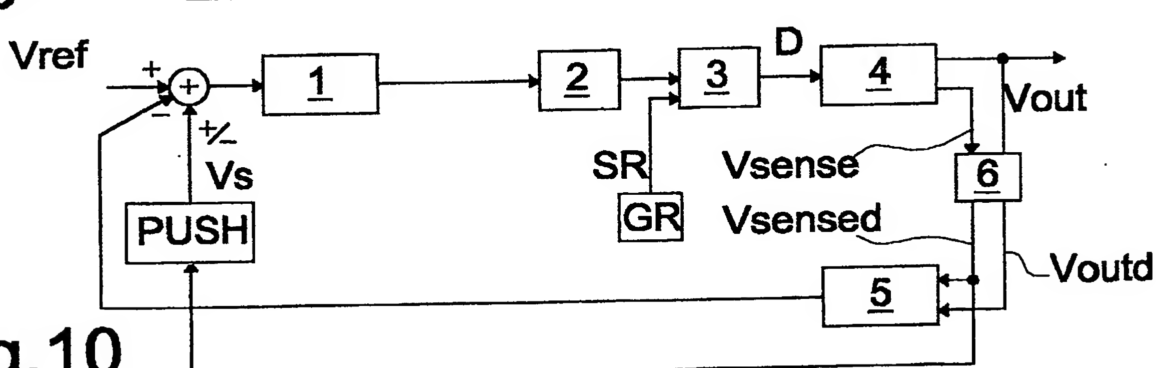

Fig.10